Investigating the Impact of Blockchain on Project Risk Management Success: A Structural Equation Model

Sevilay Demirkesen, Algan Tezel, Furkan Uysal, Zafer Ozturk

***Abstract*— Lately, the construction industry has shown a great deal of openness to utilizing novel and innovative technologies. The industry's complexity necessitates cooperative and efficient process management. Utilizing value-adding technologies is crucial in thar regard. Among them, blockchain has recently gained prominence as an enabling technology for smart contracts, and secure data management for the construction industry. This study employs a structural equation model to quantify the relationship between risk management (RM), a key project management activity, and blockchain technology. To this end, a survey was created and distributed to construction professionals. A structural equation modeling (SEM) analysis was performed on the data collected from 103 respondents. The findings show that construction project RM can be significantly affected by key blockchain features. This study contributes to the body of knowledge by presenting a conceptual framework that captures the essential elements of RM and blockchain. The results also empirically show that RM and blockchain are closely related, confirming blockchain's potential and relevance in RM applications. The paper also discusses the risks associated with adopting blockchain in the construction industry. The results of this study can help construction practitioners and policy-makers to create plans for incorporating blockchain into RM workflows.**

***Index Terms*—blockchain, construction, project management, risk management, structural equation modeling.**

I. Introduction

IMPLEMENTATION of novel techniques and digital technologies enhances the efficacy of project management [1]. Risk management (RM) also makes use of developing technologies and is recognized as a fundamental aspect of project management in the Project Management Body of Knowledge (PMBoK) Guide [2]. According to the PMBoK Guide [3], RM comprises procedures including risk identification, risk response planning, risk analysis, and risk monitoring and controlling. Digital technologies such as blockchain and artificial intelligence (AI) help project participants to manage risks and create better risk management plans [4]. Blockchain is a specific type of distributed ledger technology (DLT) that has recently drawn interest from a variety of industries [5]. In DLT, ledgers (data) are stored on separate and connected devices in a network. With its many locations and participants, DLT is essentially a decentralized database that eliminates the need for a central authority to oversee transactions. DLT transactions can be stored synchronously by computer nodes in distributed copies with cryptographic signatures confirmed by a consensus process thanks to peer-to-peer (P2P) transaction access [6]. When high levels of immutability, traceability, data security, trust, transparency, and a multi-user consensus are required (e.g., commercial transactions, contracts), DLT applications may be preferred over centralized databases [7].

Being a DLT, blockchain was first introduced with the digital currency Bitcoin by Satoshi Nakamoto in 2008 [8]. Blockchain is a specific type of DLT in the sense that data is always stored in chained blocks referencing one another, encrypted and immutable, and access to blockchain can be made public, permissionless, or permissioned [9]. Blockchain is not same as cryptocurrency (Bitcoin), which only serves as the system's functioning token [8]. Blockchain is referred to as a disruptive technology, and it is anticipated that as it gains wider adoption, it will transform several industries and workflows, and consequently catch the attention of business leaders, professionals, government officials, and academics [9-11]. Project RM activities are also a part of these developments [12,13]. However, robust empirical investigations focusing on the relationship between blockchain and RM are still scarce. This scarcity is even more conspicuous in the construction industry. Therefore, this study aims to reveal the impact of blockchain implementation on project RM success and the degree of association in between. Additionally, the study aims to disclose how blockchain can aid in different aspects of RM, as well as to highlight possible new risks and existing risks that

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can be exacerbated by blockchain. Within this framework, the research suggests some elements for implementing blockchain technology and evaluates RM success using various RM metrics. A questionnaire created using the developed framework was administered to RM experts having a background and understanding of blockchain technology in the U.S. and U.K. to gauge the impact.

This study investigates the potential connection between RM and blockchain implementation. In this respect, a framework was developed to explain the extent of association based on a set of indicators derived through an in-depth literature review. The indicators were derived considering the use of blockchain within RM processes. A questionnaire was administered to the practitioners who have experience in and knowledge of blockchain, project management, and RM processes in the construction industry. The framework's suggested measures were examined for validity and reliability using structural equation modeling (SEM). This study's primary contribution is to empirically demonstrate the relationship between RM and blockchain in the construction industry and guide blockchain implementations, encouraging the practitioners to consider blockchain as a facilitator for their RM efforts.

II. Research Background

Blockchain, which first appeared in the late 2000s and served as the foundational technology for the Bitcoin cryptocurrency, has been instrumental in facilitating the deployment of distributed ledgers [14]. It renders data exchange possible for a collection of untrusting parties (nodes) in a reliable and unchangeable way [15]. Blockchain eliminates the need for a central authority to handle and authenticate transactions. Each block in the growing chain of linked transactions is identified by a cryptographic hash connecting it to the previous block, along with the transaction data and a timestamp. Blockchain transactions are irreversible because, once they are recorded, they cannot be undone without also changing at the same time all the nodes' subsequent blocks that are recorded [16].

A peer-to-peer (P2P) computer network oversees blockchains for use. Nodes in the network cooperate to add and validate new transaction blocks according to a consensus algorithm protocol (such as proof-of-work, proof-of-stake, proof-of-authority, ripple protocol consensus, delegated proof-of-stake, stellar consensus protocol, etc.), with the cryptocurrency only serving as the system's functional token that is exchanged between the nodes [17]. Computer nodes with transparent P2P transactional access maintain the distributed blocked data copies synchronously; this access is made possible by cryptographic signatures that are verified through a consensus process. Other applications, cryptocurrencies, and private and permissioned blockchains for commercial use have all been influenced by the design of Bitcoin. Blockchain can therefore be broadly defined as an immutable, distributed, trusted, and decentralized ledger that authoritatively records transactions over decentralized P2P networks [18]. It is appropriate for recording multi-party transactions, such as payments, contracts, and commercial transactions when a high degree of trust, transparency, and provenance is needed [6,7].

Ever since its initial introduction as a public distributed ledger for Bitcoin, blockchain has garnered significant attention and earned a reputation as a disruptive technology poised to profoundly impact existing business mechanisms and contribute to the establishment of a decentralized internet [19]. Despite the initial hype, discussions centering on blockchain in the construction industry gained momentum post-2015. In the earlier stages, these discussions were more conceptual and hypothetical in nature. However, in recent years, particularly after 2019, there have been demonstrations of blockchain frameworks, prototypes, and foundational use cases [20]. The practical applications of blockchain in the construction industry can be summarized as follows [21]: (i) management of contracts and smart contracts—automated contract structures executed through computer code, (ii) information management and data recording for project management, (iii) project logistics and life-cycle management, with a specific emphasis on provenance and circularity in construction materials and components, (iv) oversight of industrial/off-site construction transactions, (v) stakeholder management, (vi) intelligent systems, (vii) integration of blockchain with other technologies such as Building Information Modeling (BIM) and digital twins, (viii) management of construction procurement, supply chain, and logistics, and (ix) establishment of decentralized autonomous organizations (DAOs) for the industry, with a focus on implementing crypto-economics and data governance [22].

Moreover, according to an Arup industry report by Nguyen et al. [23], the built environment can be categorized into five markets: cities, energy, property, transport, and water. Within each of these markets, the report highlighted the potential applications of blockchain in five subcategories, including smart cities with integrated Internet of Things (IoT), energy microgrids, property transactions and sales, transportation, material passports, utility contracts, and billing for water. Most of these applications are still in the conceptual or early prototype development stages, as indicated by the same report, with commercialization generally not expected before 2025 at the earliest [23]. Although some early foundational use cases have emerged since the report [24], the forecast for future commercialization remains unchanged. This level of technological readiness aligns with the development of blockchain applications in these specific market segments. Several studies have also sought to assess blockchain readiness in specific national contexts to enhance the understanding of its applicability in the construction industry, such as the case of China as outlined in Gao et al. [25]. Advocates for blockchain technology in construction are growing in number, exemplified by the likes of the Blockchain Construction Consortium in the UK. However, from a business perspective, the cost of deploying blockchain must be justified by the tangible and intangible benefits derived from its features, as the decision to adopt blockchain technology ultimately represents an investment. Furthermore, practitioners in the construction industry need and require leadership, guidance and incentives from policy-makers for large-scale blockchain trials [7].

Cryptocurrency, on outcome of blockchain, is now considered an avenue for uncertainties in policy RM. Especially during more volatile economic times, investors tend to either limit their holdings, bide their time until the current turbulent circumstances subside, or seek out appropriate global risk-mitigation tactics. It's interesting to note that, particularly during the era of increased uncertainty, the Bitcoin market emerged as a RM tool for local and foreign investors in stock and commodities markets worldwide [26]. Shahbazi and Byun [27] stated that cryptocurrency is one of the most well-known financial states in the world, which presents several hazards that affect risk auditors' intrinsic evaluation. They further implied that the emergence of cryptocurrencies has always presented a significant risk to the banking industry in terms of potential money laundering. In the context of financial support institutions such as anti-money laundering, banks, and bank secrecy function as risk specialists, bank managers, and compliance officers who investigate linked cryptocurrency transactions and users who conceal illicit cash.

A significant portion of the studies investigated the blockchain and RM relation in the supply chain context. Alkhudary et al. [28] discussed that blockchain technology offers options to assist the stakeholders in these supply chains in improving security and transparency since blockchain is a database that securely, openly, and irrevocably registers digital assets. Feng et al. [29] proposed a cutting-edge strategy for managing cyber risks in blockchain-based services. Specifically, they implemented cyber-insurance as a financial instrument to mitigate the cyber risks arising from attacks on blockchain networks. They modeled the association among the users, blockchain provider, and the cyber-insurer, where the users follow to ascertain their demand for the blockchain service, with the blockchain provider and cyber-insurer taking the lead in setting their price and investment plans. In general terms, blockchain can help to mitigate the risks associated with privacy and security challenges, contracting, monitoring counterfeiting, and traceability in supply chain management [30].

Blockchain has also the potential to alleviate various issues in the construction industry stemming from a lack of trust, transparency, data security, access to finances and resources, and the existence of intermediaries and gatekeepers [31]. A study by Kim et al. [32] investigating blockchain adoption in project management application domains in the construction industry showed that blockchain holds a reasonable potential for the RM domain in terms of applicability and impact. This blockchain and RM application becomes more relevant when recorded data is of a sensitive nature [33]. However, despite the recently surging research on blockchain, blockchain and RM is one of the areas in the construction industry where a lack of investigation is apparent [34]. Furthermore, it is expected that wider blockchain diffusion in the industry will give rise to new risks and exacerbate some of the existing risks in the future [35].

Given this background, it is observed that most studies investigating the RM and blockchain association focus on supply chain management, cyber risks, and transactional risks. There is also a lack of empirical research specifically on the blockchain and RM interplay in the construction project management domain. Discussions on blockchain and RM in the construction industry have remained mostly anecdotal and conceptual in nature. Therefore, this study rather focuses on the blockchain and RM interaction from a different perspective, where the extent of this association was statistically evaluated on a framework developed based on the components derived for blockchain implementation and RM.

III. Research Framework

The elements necessary for a successful RM and blockchain deployment are included in the framework this study proposes. Several components were derived in the first step from a thorough review of the literature focusing on the success of RM and blockchain implementation. The success of RM and the implementation of blockchain are factors, and 18 components were derived for these two factors. Following the completion of a preliminary research involving five academics and three professionals (a board member and two project managers) from the construction industry, some components were either merged or eliminated to represent their respective roles more accurately. The academics were selected based on the criteria of having knowledge in blockchain and digital construction research and implementation. A minimum of two completed research projects on digital construction was sought when arriving at these professors. Ultimately, twelve model constituents were acquired. Each factor's fundamental elements are recognized and discussed. To that end, Table I displays the blockchain parameters that were used in this investigation in terms of their use in RM.

This study measures the impact of blockchain implementation on RM success. Several studies highlighted that blockchain has a significant impact on RM [30, 36, 37]. According to the definition provided in PMBoK Guide [38], RM consists of successful management of processes such as risk identification, analysis, response planning, and controlling. Table II presents the components developed for the success of RM in terms of blockchain implementation.

Given this background, it can be asserted that there is some research in RM and blockchain, but the association between them has not been widely assessed yet, particularly for the construction industry. For example, Etemadi et al. [30] investigated the use of blockchain to predict disruptions in supply chain RM. Alamri et al. [39] proposed a cybersecurity RM framework for blockchain implementations. Rauniyar et al. [40] further studied RM of supply chains with blockchain technology.

TABLE I
COMPONENTS OF BLOCKCHAIN IMPLEMENTATION

No	Blockchain implementation	References
1	*Auditability:* Secured transaction records, including a chronological event log of transactions, result in heightened traceability and origin verification of transactions	[6, 41-43]
2	*Security:* Ensuring the safeguarding of digital data from hacking and cyber threats, the information is made tamper-proof. Encryption enables the confidentiality of private data, while digital signatures provide assurance of non-repudiation, authenticity, and data integrity.	[19, 31, 41, 44]
3	*Automation:* Automated documentation, execution, and retrieval of transactions through smart contracts lead to heightened automation in the transactional process.	[16, 19, 45-47].
4	*Authenticity and decentralization:* Engaging in decentralized peer-to-peer transactions means that traditional centralized systems cannot guarantee the integrity and authenticity of equipment security information, as they lack flexibility as a solution	[6, 7, 19, 22, 41, 47, 48].
5	*Anonymity and privacy:* In order to protect their privacy and facilitate identity verification by third parties, individuals have the option to remain anonymous.	[6, 19, 22, 41].
6	*Configurability:* Blockchain architectures are dynamic and can be configured to meet various needs and adapt to different use scenarios, offering increased flexibility for factors such as security, speed, scalability, and more.	[6, 19, 49, 50, 51]
7	*Trustworthiness:* Blockchain can improve the reliability and trustworthiness of applications, fostering increased accountability in transactions. For new data to become part of the authoritative blockchain, it requires approval from the majority of blockchain users, making it a trusted source of truth. With the ability for participants to access the digital ledger, transaction transparency is enhanced, and the degree of transparency can be adjusted as needed.	[18, 19, 20, 31, 41-43, 50, 52]

Despite some studies investigating blockchain implementation and its potential impacts on RM, there is still a lack of research in terms of investigating the association between blockchain implementation and RM success, and its extent. Therefore, this study aims to provide a better understanding of blockchain implementation attributes along with its impact on RM success. In this respect, the study develops specific attributes and visualizes the relation between blockchain and RM by quantifying the effects.

TABLE II
COMPONENTS OF RISK MANAGEMENT SUCCESS

No	Risk management success	References
1	*Risk Identification:* This is the precise identification and recording of project risks that could have a negative impact on the project's future. A well-executed risk identification process is critical to the successful completion of projects.	[53-56].
2	*Risk Analysis:* Risk analysis, impact estimation, evaluation of the likelihood of occurrence and consequences of the risk, risk prioritization to determine the most significant risks, and risk evaluation are the steps in RM. A key factor in the success of RM is thorough risk analysis.	[53, 54, 57-59].
3	*Risk Response Planning:* Planning for risk response entails identifying potential threats to the projects and anticipating risks before they materialize. Developing proactive approaches to RM and enhancing the efficacy of RM procedures are imperative.	[60-63].
4	*Risk Allocation:* The process of assessing the risks identified and allocating them to the parties best suited to bear them is known as risk allocation. Risk allocation is necessary and important for properly managing projects.	[54, 55, 58, 64].
5	*Risk Control:* This refers to the implementation of risk response plans, monitoring critical risks, and taking corrective action when required. Risk control is an essential part in successful RM.	[53; 65-67].

The evidence presented in the literature regarding the effect of blockchain implementation on RM success forms the basis of the following hypothesis (*H1*).

H1: Effectiveness of blockchain implementation has a direct and positive effect on risk management success.

The conceptual framework and developed indicators for this study are shown in Fig. 1.

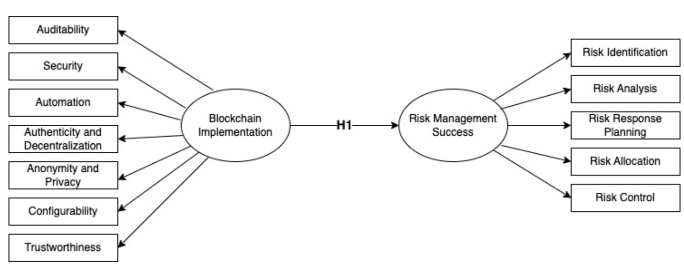

Fig. 1. Conceptual framework and indicators.

IV. Research Methodology

An online questionnaire was designed and administered to project management professionals practicing RM in the U.S. and U.K. construction industries, and with knowledge and engagement in blockchain (Please see Appendix). The questionnaires were addressed to project management professionals working at large construction firms, and they were selected (selective sampling) by their years of experience in project management and engagement with blockchain initiatives and communities. To this end, construction professionals with minimum 5 years of construction project management experience, and who have actively been engaged with the blockchain communities in the U.S. and U.K. were selectively targeted. As construction professionals might not have a sound technical background on blockchain, the questions were formulated to capture the high-level blockchain features relevant for RM as identified in Table 4, which do not require any DLT specific technical expertise. From the 270 questionnaires sent, 123 were returned resulting in a response rate of 46%. The analysis did not include however the responses with missing data or the outliers; therefore, there are 103 responses used in this study in total. Respondents were asked to fill in the questionnaire considering their knowledge of blockchain along with RM practices in their projects.

The questionnaire was divided into two sections: (i) general information about the respondent and the organization they work at, and (ii) variables about the performance of RM and blockchain. Using a Likert scale of 1 to 5, the respondents were asked to rate their RM procedures according to the specified variables (1: very low, 2: low, 3: medium, 4: high, 5: very high) based on their experience and understanding. All respondents have more than 5 years of experience with RM, project management, and blockchain knowledge and engagement.

Data gathered from the 103 respondents was analyzed using the SEM tool AMOS (Analysis of Moment Structures). SEM is a multivariate statistical methodology that investigates a structural theory based on a phenomenon using a confirmatory approach. Observed and latent variable hypotheses are tested using SEM [68-71].

There are several names for SEM, including "Causal Modeling," "Causal Analysis," "Simultaneous Equation Modeling," "Analysis of Covariance (ANCOVA) Structures," and "Confirmatory Factor Analysis" (CFA) [72-74]. By incorporating confirmatory factor analysis (CFA) and path analysis to evaluate a latent variable through numerous observed variables, SEM has become a prevalent analytical approach [75]. This research deems SEM as a suitable method, given the diverse dimensions within the various variables illustrated in Figure 1. Accurate construct-level results can be obtained by utilizing multiple indicator variables for a construct simultaneously using SEM. Furthermore, SEM produces unbiased results by taking measurement error into account about the measurement error components of observed variables. In conclusion, SEM provides several benefits for modeling and analyzing intricate patterns of interactions, allowing for a simultaneous examination of multiple hypotheses [76].

The two models that make up SEM are the measurement and the structural [70]. While the structural model shows the causal relationships between latent variables, the measurement model uses observed variables to measure the hypothetical constructs [75]. It is necessary for SEM to validate the proposed constructs. A construct's validity is determined by how well its instruments measure it. Construct and content validity are the two categories of validity in a structural model that require testing. "Degree of agreement of indicators hypothesized to measure a construct and the distinction between those indicators and indicators of a different construct" is the definition of construct validity [77]. Construct validity needs to be achieved for model testing to be reliable. Content validity indicates how well a construct is represented by its indicators, which also needs to be satisfied for a reliable model testing [78].

V. Data Analysis and Findings

All respondents work as senior-level managers for major firms. The respondents' roles are project managers (58%), project directors (33%), and board members (9%) with an average year of experience of 16 years. It was found that 80% of the respondents work at construction firms, whereas the remaining 20% work at engineering and architecture firms. 83% of the respondents indicated that the firms they work for have been operating in the construction industry for more than 50 years showing a significant amount of expertise in the field. The area of the expertise of the firms is infrastructure (50%), transportation (25%), building (17%), and industrial (8%) construction. The average annual turnover of the firms was reported as 196 million USD. The average number of employees was found to be 240. Table III presents the participant demographics, such as gender, age, education, and years of experience in blockchain and RM.

Data regarding the degree of success attained for each developed component was gathered via the questionnaire. The components were rated based on the respondents' understanding of the use of blockchain. The ratings for every aspect of the blockchain implementation are shown in Fig. 2.

TABLE III
PARTICIPANT DEMOGRAPHICS

Measures	Items	Frequency
Gender	Male	73
	Female	30
Age	26-30	9
	31-35	13
	36-40	19
	41-45	27
	46-50	25
	51-55	9
	>56	1
Education	BSc	69
	MSc	23
	PhD	11
Years of experience in blockchain	2-5	80
	>5	23
Years of experience in risk management	5-10	47
	10-15	23
	15-20	19
	>20	14

Each component's ratings are shown based on the acronyms that are used for each one (B1: Auditability, B2: Security, B3: Automation, B4: Authenticity and Decentralization, B5: Anonymity and Privacy, B6: Configurability, B7: Trustworthiness). All the components are rated between 4.30 and 3.50 in Fig. 2, and the Cronbach's alpha value of 0.899 indicates that the components are reliable in terms of explaining their construct.

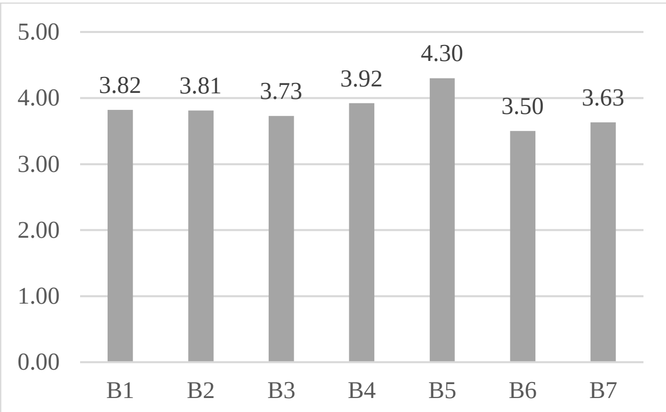

Fig. 2. Ratings for the components of blockchain implementation.

Fig. 3 presents the ratings for each component of RM success. Abbreviations were used for each component (R1: Risk identification, R2: Risk Analysis, R3: Risk Response Planning, R4: Risk Allocation, R5: Risk Control) and the ratings are presented accordingly. Figure 4 indicates that the respondents were more successful in risk identification than risk response planning.

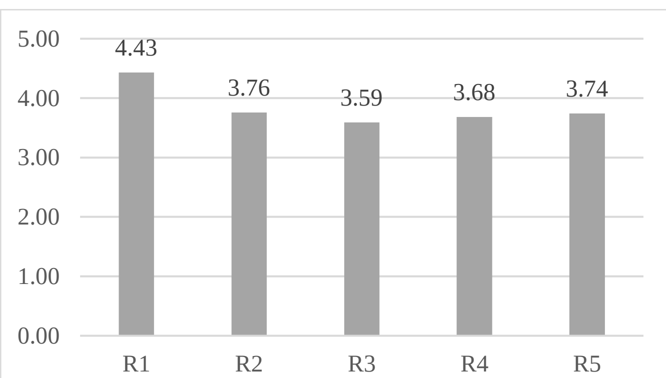

Fig. 3. Ratings for the components of risk management success.

In this study, researcher judgment and insight are used since there is no rigorous statistical test for content validity [79]. To determine the indicators of each construct, a thorough assessment of the literature was done. The indicators were updated with the help of three project management professionals from the construction industry as well as five university academics who participated in the pilot tests to determine the constructs' content validity.

Some of the components were merged into the other components since they were deemed repetitious after discussions with the professionals, academics, and based on subjective assessment. For instance, the transparency component was merged into trustworthiness being an essential element of trust. Moreover, veracity of data was considered part of security as advised by the experts. A similar approach was adopted for the RM success construct. Risk monitoring was considered part of risk control, and risk evaluation was named as risk analysis after the feedback provided.

Construct validity requires reliability, discriminant validity, and convergent validity. The test of convergent validity determines if the items used to measure one latent variable also form another. Convergent validity is assessed by factor loading analyses and goodness of fit indices. Discriminant validity, as opposed to convergent validity, looks at whether two measurements reveal statistically distinct patterns for identifying a construct. Discriminant validity is assessed by looking at the correlations between the measures of a construct [71]. Examining factor loadings is necessary in confirmatory factor analysis (CFA) to eliminate items from the model that are statistically insignificant. This contributes even more to improving the fit and internal reliability indices.

Table 4 demonstrates the factor loadings for the latent and constituent variables of the model. The factor loadings were derived using the AMOS tool of SPSS. A CFA was conducted to generate the factor loadings of the model variables. According to the table, all the factors are well represented by their variables by the factor loadings of each factor.

Some slight differences were observed with respect to the placement of some variables on their factors. For example, anonymity and privacy (factor loading: 0.961) have a stronger association with blockchain implementation than configurability (factor loading: 0.879). Risk identification (factor loading: 0.966) has a stronger association with RM success than risk response planning (factor loading: 0.886). The variables for each component were all deemed to be legitimate indicators despite having slightly varied locations on their representative factors after using a comparable evaluation standard to the two factors. As a result, it can be inferred that

TABLE IV
LATENT AND CONSTITUENT VARIABLES OF THE MODEL

No	Model variables	Factor loadings
F1	*Blockchain Implementation*	
V1	Auditability	0.900
V2	Security	0.901
V3	Automation	0.899
V4	Authenticity and Decentralization	0.909
V5	Anonymity and Privacy	0.961
V6	Configurability	0.879
V7	Trustworthiness	0.896
F2	*Risk Management Success*	
V8	Risk Identification	0.966
V9	Risk Analysis	0.905
V10	Risk Response Planning	0.886
V10	Risk Allocation	0.897
V11	Risk Control	0.888

the components chosen for each construct are reliable indicators and accurately represent their construct.

The constructs' fit indices and reliability values are shown in Table 5. The standard definition of reliability is the constructs' internal consistency. Reliability in a structural model is defined as the strength of the direct relationships, ignoring the error terms, with the measure for which the reliability is evaluated [68]. Cronbach's alpha is used to assess the reliability test in this investigation. The reliability of the constructs is deemed satisfactory when each construct's Cronbach's alpha coefficient is greater than 0.7 [80]. In light of the results of the reliability analysis, it was concluded that the constructs of blockchain implementation and RM success are consistent.

The Chi-square (X2) test was used to assess the goodness of fit. In SEM, X2 is used to find any meaningful difference between the predicted and actual matrices. At the lower values of X2, a better fit is seen. An X2/df (degree of freedom) ratio is recommended as a fit measure in AMOS. An X2/df ratio less than 5.0 is regarded as falling within an acceptable range (Marsh and Hocevar, 1985). The study's model exhibits a X2/df ratio of 2.851 for the blockchain and 2.803 for the RM construct. This shows that the model and the data fit each other well.

TABLE V
RELIABILITY AND FIT INDICES FOR THE CONSTRUCTS OF THE MODEL

Index	Recommended value	F1	F2
Cronbach's Alpha	> 0.7	0.889	0.908
X2/df	< 5.0	2.851	2.803
RFI	> 0.90	0.931	0.947
CFI	> 0.90	0.952	0.969
TLI	> 0.90	0.923	0.937
RMSEA	< 0.10	0.094	0.097

The relative fit index (RFI) [81], comparative fit index (CFI) [82] and Tucker-Lewis index (TLI) [83]. can be used to compare the proposed model to the null or independence model. Values of these indices range from 0 to 1.0, with values near 1.0 denoting a strong fit. A parsimony-adjusted statistic with an integrated model complexity compensation is the root mean square error of approximation (RMSEA) [84]. An acceptable fit was previously determined to be with an RMSEA cutoff value of 0.10 [70].

Table 5 shows that all constructs' reliability is satisfied in terms of supporting Nunnally's [80] recommendation, where all Cronbach's alpha values are greater than 0.7. This suggests that when the measurement model exhibits a good fit to the data, all fit indices are in acceptable ranges. Ultimately, it was identified that each construct's RMSEA value is below the cutoff point, indicating a good fit between the data and the model.

The relationships between the confirmed constructions are examined by SEM. In this context, the relationship between successful RM and blockchain was investigated. Fig. 4 displays the suggested correlations with their path coefficients. The endogenous variables in Fig. 4 are auditability, security, automation, authenticity and decentralization, anonymity and privacy, configurability, and trustworthiness, while the exogenous variables are the success of RM and blockchain engagement. The numbers on the arrows, which show the direction of effect between the model's parameters, correspond to the path coefficients. Path coefficients are equal to regression weights in SEM, with the exception that there is no intercept term.

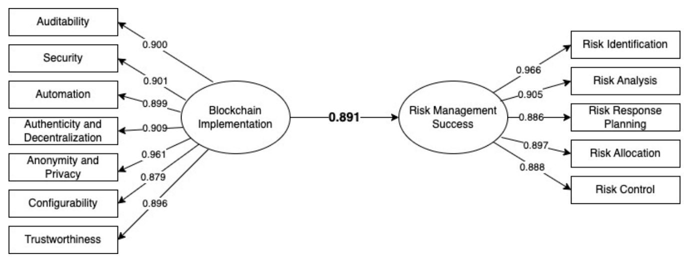

Fig. 4. Blockchain and risk management framework with path coefficients.

The results were assessed using the Murari [85] interpretation guidelines. As per the guidelines, there is a weak association, a moderate association, and a high association between variables when the path coefficients range from 0.1 to 0.3; 0.3 to 0.5, and 0.5 to 1.0 respectively. The study found that the application of blockchain has a significant influence on RM success (0.891) based on these guidelines.

The model's fit indices and reliability values are displayed in Table 6. Some researchers adopt a threshold value of 0.95 for most of the indices in SEM, even though there is no universal agreement on the threshold values of fit indices [86, 87].

As suggested by Nunnally [80], Table 5 shows that the Cronbach's alpha values are higher than 0.7. For the RFI, CFI, and TLI values—all of which were found to be approximately 0.9—a reasonable fit of the model to the data was found. Furthermore, it was found that the RMSEA values are lower than that of Kline's [70] recommended threshold value. In the first phase, 123 responses were collected. There are 103 responses in total used in the analysis because the responses with missing data or outliers were excluded from the analysis. The outliers were detected using box plot analysis in SPSS. When the data was additionally checked for normality, it was found to be regularly distributed. The correlation matrices for each construct were finally calculated, and it was found that none of them have intercorrelations greater than 0.90, indicating the lack of multicollinearity [88]. This shows that the fit between the initial and final model is satisfactory.

TABLE VI
RELIABILITY AND FIT INDICES

Index	Recommended value	Model
Cronbach's Alpha	> 0.7	0.901
χ^2/df	< 5.0	2.827
TLI	0 (no fit) to 1 (perfect fit)	0.931
IFI	0 (no fit) to 1 (perfect fit)	0.957
CFI	0 (no fit) to 1 (perfect fit)	0.961
RMSEA	< 0.10	0.095

VI. Discussion

The analysis of the model showed that there is a significant link between blockchain and RM success. This reveals that blockchain technology can be a promising means for managing risks in construction projects, leading to enhanced project success. The results confirm that blockchain is relevant and can be an enabler for the project RM process. These results are worth discussing for the fact that industry practitioners tend to rely more on digital technologies, and their associated methods and practices for achieving higher rates of project success [89, 90].

Given the relationship between blockchain implementation and RM success, it is important to discuss how each component of blockchain characteristics can interplay with RM effectiveness.

A. Audibility

Auditability refers to protected transaction histories in blockchain supporting high-value transactions [6, 19, 41]. Provided with a high factor loading (0.900), auditability was found to be one of the key elements of blockchain implementation. It is also apparent that auditability has an important impact on managing risks. Popchev et al.[56] showed that the characteristics and functions of internal audit and internal control have an important impact on risk identification, risk management, and mitigation processes. Indeed, auditability will improve internal control and tracking of RM actions, and decisions in the longer term. Increased audibility will accelerate the RM process.

B. Security

Blockchain technology provides enhanced security with its DLT characteristics, which project managers can use for mainly application-based interactions [91]. The analysis of the model results in this study revealed that security is a key component of blockchain implementation with a factor loading of 0.901. Ghazal et al. [92] discussed that project management is impacted by security issues while employing blockchain technology and the internet of IoT by raising the assessment of risks through the medium and high clusters of risk. Blockchain categorizes the risks that may have an impact on a project's success and results. As a result, projects' technical and security concerns are addressed, where these technologies affect business processes [12]. To this end, blockchain may contribute to maintaining a secure RM infrastructure and transaction backbone against data breeches or hacks.

C. Automation

Automating processes refer to automatic recording, executing, and retrieving transactions in blockchain technology [19]. The analysis results showed that automation is an important component of blockchain implementation (factor loading:0.899). The effect of automating transactions in various processes has already been discussed in different studies. Hamledari and Fischer [93] demonstrated that construction progress payments can be automated through blockchain enabling smart contracts. They further stated that smart contracts can automate collaborations, where reporting overheads are reduced, and the risks are transferred. El Khatib et al. [12] also reported that blockchain technology helps to mitigate the project failure probability. Automating processes through blockchain is expected to foresee risks and take preemptive action before they turn into irrecoverable mistakes. In that regard, automation through blockchain can reduce risks associated with tasks completed through human intervention, such as human errors and sabotage, and streamline RM activities.

D. Authenticity and Decentralization

Authenticity and decentralization are two important features of blockchain technology referring to verification of users and transferring control to a distributed network. This is essential for the integrity and genuineness of securely stored information [6, 22]. In fact, authenticity and decentralization was found to be one of the key elements of blockchain implementation (factor loading: 0.909). These two features are also effective in managing risks, especially in supply chain management. Gao [94] discussed that since a blockchain based platform is decentralized, all transactions may be self-certified, automatically completed through smart contracts, and do not need third party intermediaries, which results in reduced costs, improved security and provenance. The author further noted that asset information can be traced and viewed in real time to improve asset financing capabilities thanks to blockchain technology. First, by eliminating redundant links, reducing manual operations, and lowering costs, the risk becomes more manageable. Second, the information is symmetrical, solving the trust problem of all parties in the transaction chain.

E. Anonymity and Privacy

In blockchain arrangements, users can become anonymous protecting their privacy [6, 41]. In this study, anonymity and privacy was found to be the most influential component of blockchain implementation with a high factor loading (0.961). Indeed, Khalilov and Levi [95] noted that although users can choose to become anonymous in blockchain, since the transactions are publicly available, transactions can be tracked or linked. Therefore, the authors highlighted that anonymity and privacy is still an issue that needs careful consideration in blockchain arrangements and needs to be further improved to provide secure transactions. Anonymity and privacy can further facilitate RM processes since a privacy preserving blockchain will eventually lead to enhanced trust in operations and secure transactions. The level of anonymity and privacy can be also changed as needed by different blockchain arrangements.

F. Configurability

Blockchain technology provides a trusted data management scheme, where a configurable blockchain architecture is established based on a mutual authentication protocol, flexible consensus, and deployment [96]. Configurability was found to be an essential element of blockchain implementation with a factor loading of 0.879. Indeed, the configurable infrastructure brings certain advantages for users, where users save time and develop trust within the network, by their business needs. The technologies that are available for self-sovereign identity authentication do not provide the requisite flexible challenge set configuration, whereas blockchain implementation can help to create a multi-factor challenge-set self-sovereign identity authentication [97]. The configurability in blockchain is also considered an important facilitator for managing the risk chain [98]. This in turn enhances the capacity for managing risks. Also, with different blockchain configurations available, risks associated with a certain configuration can be more easily avoided.

G. Trustworthiness

Blockchain helps to improve the trustworthiness of applications, where there is a single source of trust enhancing the transparency of transactions [41, 99, 100]. Trustworthiness was found to be a critical component of blockchain implementation with a factor loading of 0.896. Zavolokina et al. [101] discussed that the process of creating and preserving transactions in a ledger is visible and unchangeable, which establishes the trust that blockchain technology brings. This in turn affects better management of risks in the context of an RM scheme. With a secure, transparent, and trustworthy system, users can confidently execute RM workflows.

The evaluation of the items by the participants in terms of blockchain implementation and RM components supports the claim that blockchain can be used to enhance the effectiveness of RM, where more secure transactions are realized through authenticity, decentralization, trustworthiness, and privacy. Revealing the significant impact of blockchain in RM, the results of this study can be used to devise new strategies and workflows, and to encourage practitioners, researchers, and policy makers in the construction industry to pay more attention to the blockchain and RM link. The findings are also in line with the conclusions in Kim et al. [32] study in terms of blockchain's potential for RM as part of the project management domain.

Although a strong link between blockchain and RM success was identified in this study, implying the technology's promising potential in relation to RM, blockchain's limitations and the risks associated with adopting blockchain should not be overlooked [19]. Not all transactions are suitable for blockchain, and to take full advantage of blockchain's features, the technology should not be merely treated as a distributed database. From an RM perspective, this means that practitioners should carefully identify where and for what data types in the RM process blockchain is best suited. In general terms, blockchain is suitable for multi-party and sensitive (e.g., commercial) transactions that will be referred to over a longer period of time [7]. To this end, blockchain can be better suited for recording a risk identification and response log for critical risks in large and complex projects. Alongside this, the risks associated with adopting the technology in a real-life situation should be fully understood. For instance, as blockchain records are virtually immutable, risks associated with recording the correct data in the first place are exacerbated in a blockchain environment. Furthermore, new risks such a perverting the law or operating outside of regulations, fraudulent activities, and abuse of blockchain platforms, increased job security concerns for certain professions, scalability risks in implementation, money laundering risks, theft of currencies, double-spending and wallet security issues and conflictions with legacy IT systems should be paid attention to while implementing blockchain in the construction industry [35].

VII. Conclusion

This study investigated the impact of blockchain on RM success. In this respect, a questionnaire was formed and administered to project management professionals working in the construction industry. The data collected was used to analyze the hypothetical model, which aimed to measure the impact of blockchain implementation on RM success and reveal the extent of the relationship between these two factors.

The analysis of the data showed that blockchain can have a significant and positive impact on RM success. The components developed for blockchain implementation such as audibility, security, authenticity, and trustworthiness were found to be well-explaining components of their corresponding factor. Moreover, the components developed for RM success such as risk identification, risk allocation, and risk control were also found as essential components to explain RM success. In this sense, one can claim that blockchain helps to avoid certain data management risks related to post-data recording, such as data breach, data fraud, and data loss. Moreover, blockchain implementation can help organizations to securely function their systems thanks to its trustworthy and transparent nature. These features of the technology can help industry practitioners to better manage RM data, especially for large and complex projects, where multiple stakeholders take part in sensitive data transactions. Indeed, the dynamic and fragmented nature of the construction industry necessitates the use of properly functioning systems to mitigate risks arising from data recording, transactions (i.e., smart contracts), and data management. Therefore, careful consideration must be given to practical issues such as which aspects of the RM process should be recorded on blockchain, what data will be stored on and off blockchain, the technical requirements for the blockchain architecture needed for such an application, and how work processes and human resources will be coordinated with the adoption of blockchain technology. In line with this, the risks associated with adopting this nascent technology should be fully understood by researchers and practitioners.

Given this background, researchers and policymakers can benefit from the findings of this study to develop more research in a wider framework including blockchain and RM, and devise strategies accordingly. This could help construction organizations to adopt blockchain to its full advantage and improve their RM capabilities. As all the respondents are actively interested and engaged in blockchain, some response bias can be found in the responses, which poses a limitation for this study. Future research can focus on the suitability of blockchain for certain RM activities and what RM activities should be prioritized for blockchain implementation in construction, as well as different blockchain configurations for construction project RM. Also, validating the findings presented in the paper through case or action-based studies will be useful. Alongside this, research on developing blockchain-based prototypes to facilitate the RM process in construction projects should increase. More research on blockchain-induced risks from a construction industry perspective is also needed.

	Very low	Low	Medium	High	Very High
Risk Identification	□	□	□	□	□
Risk Analysis	□	□	□	□	□
Risk Response Planning	□	□	□	□	□
Risk Allocation	□	□	□	□	□
Risk Control	□	□	□	□	□

APPENDIX

Blockchain-Risk Management Questionnaire

Part I

1. Field of operation of your firm.
□ Engineering
□ Architecture
□ Construction

2. Number of years that your firm has been operating in the construction industry.
□ 0-10
□ 10-20
□ 20-30
□ 30-40
□ >50

3. Area of expertise of your firm
□ Infrastructure
□ Transportation
□ Building
□ Industrial
□ Water Structures
□ Other

4. Annual turnover of your firm…………………………………………………..

5. Number of total employees of your firm…………………………………………

6. Your gender
□ Male
□ Female

7. Your age
□ 26-30
□ 31-35
□ 36-40
□ 41-45
□ 46-50
□ 51-55
□ >56

8. Your education
□ BSc
□ MSc
□ PhD

9. Your years of experience in blockchain
□ 2-5
□ >5

10. Your years of experience in risk management
□ 5-10
□ 10-15
□ 15-20
□ >20

11. Your position at the firm
□ Owner
□ Board Member
□ Director
□ Manager
□ Other

12. Your years of experience in the construction industry
□ 0-5
□ 5-10
□ 10-15
□ 15-20
□ >20

13. Type of the project
□ Infrastructure
□ Transportation
□ Building
□ Industrial
□ Water Structures
□ Other

14. Role in the project
□ Contractor
□ Designer
□ Client
□ Sub-contractor
□ Other

Part II

15. Rate your success level for the listed blockchain parameters.

16. Rate your success level for the listed risk management parameters.

	Very low	Low	Medium	High	Very High
Auditability	□	□	□	□	□
Security	□	□	□	□	□
Automation	□	□	□	□	□
Authenticity & Decentralization	□	□	□	□	□
Anonymity & Privacy	□	□	□	□	□
Configurability	□	□	□	□	□
Trustworthiness	□	□	□	□	□

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